Hands-on with

ACT-UP,

a Cognitive Toolbox for Scalable Models

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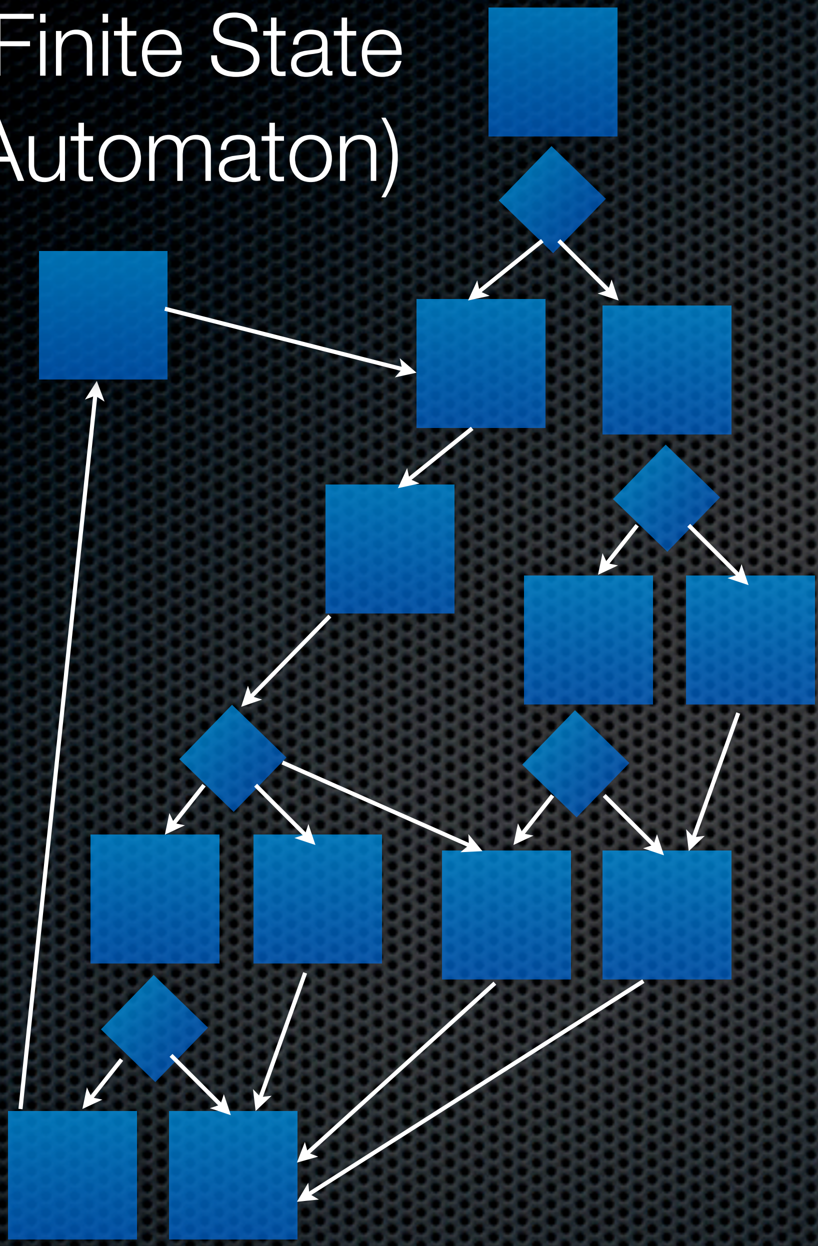
Some goals

- Enable the implementation of more complex ACT-R models
- Scale up cognitive models to simulate learning / adaptation in communities (e.g., about 1,000 models in parallel)
- Treat models as hard claims
  - Evaluate each specified component against data
  - Underspecify the rest and fit free parameters

The Argument

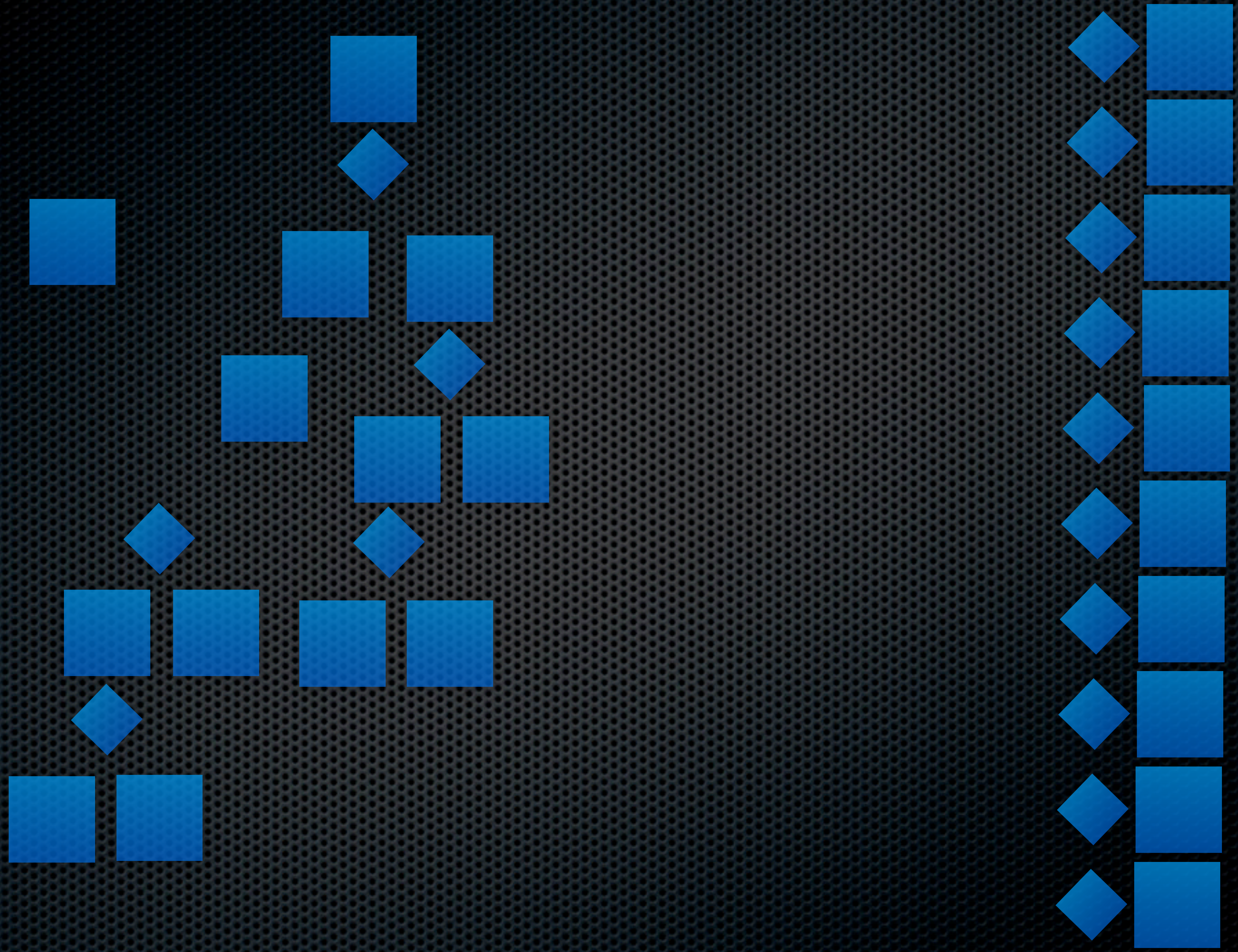
- **Constraints:** Architectural advances require further constraints
- **Scaling it up:** Complex tasks, broad coverage of behavior (e.g., linguistic), use of microstrategies and predictive modeling may serve to motivate further architectural constraints
- **Difficulties:** ACT-R is heavily constrained already, and models are difficult to develop, reuse and exchange

Flow Chart (Finite State Automaton)

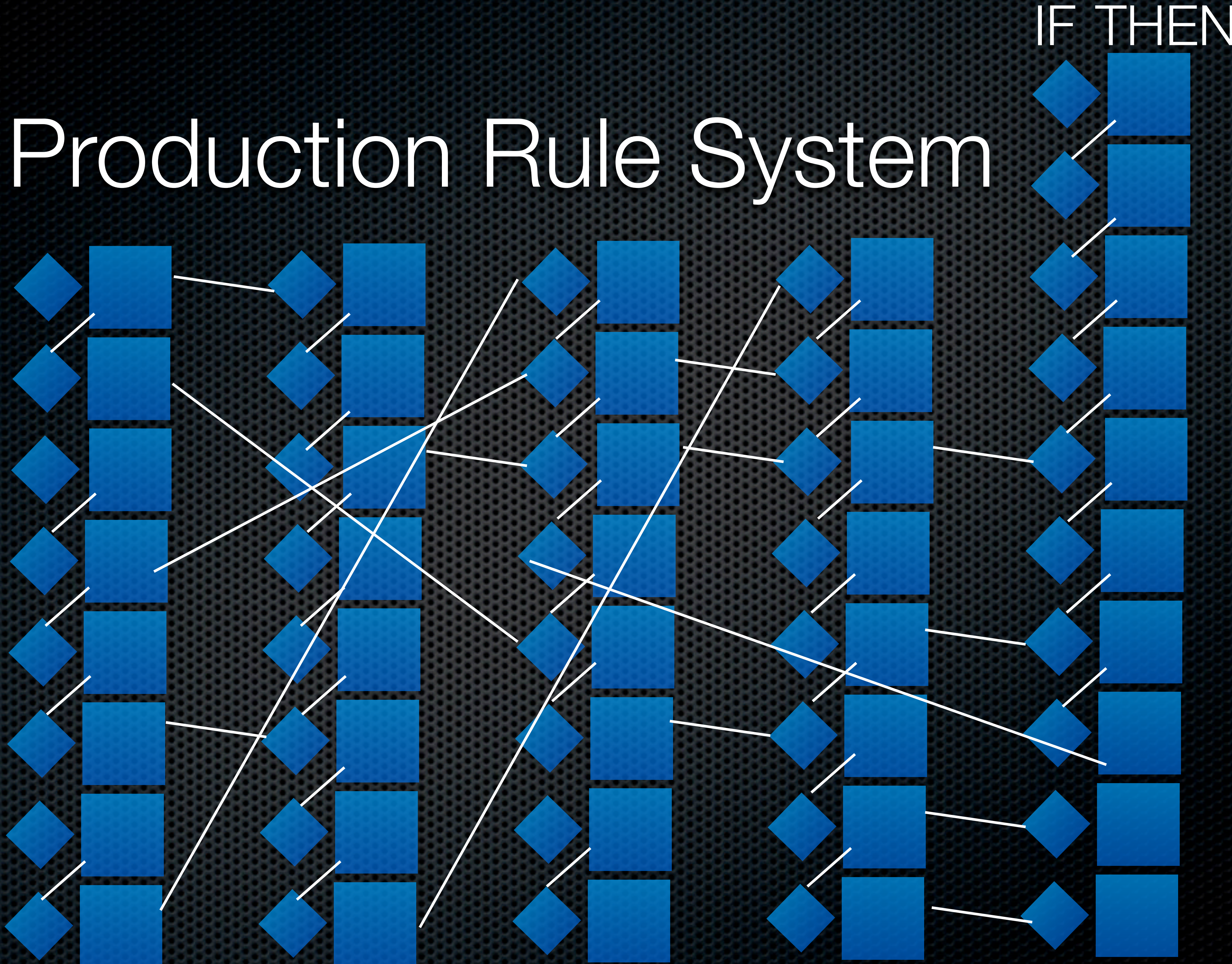


- A flow-chart describes an algorithm (or a cognitive strategy)
  - Decision-making points and states
- Not easy to reuse: it fails to capture generalizations
- Computer Science: pre-Object Orientation, pre-Functional Programming

IF THEN



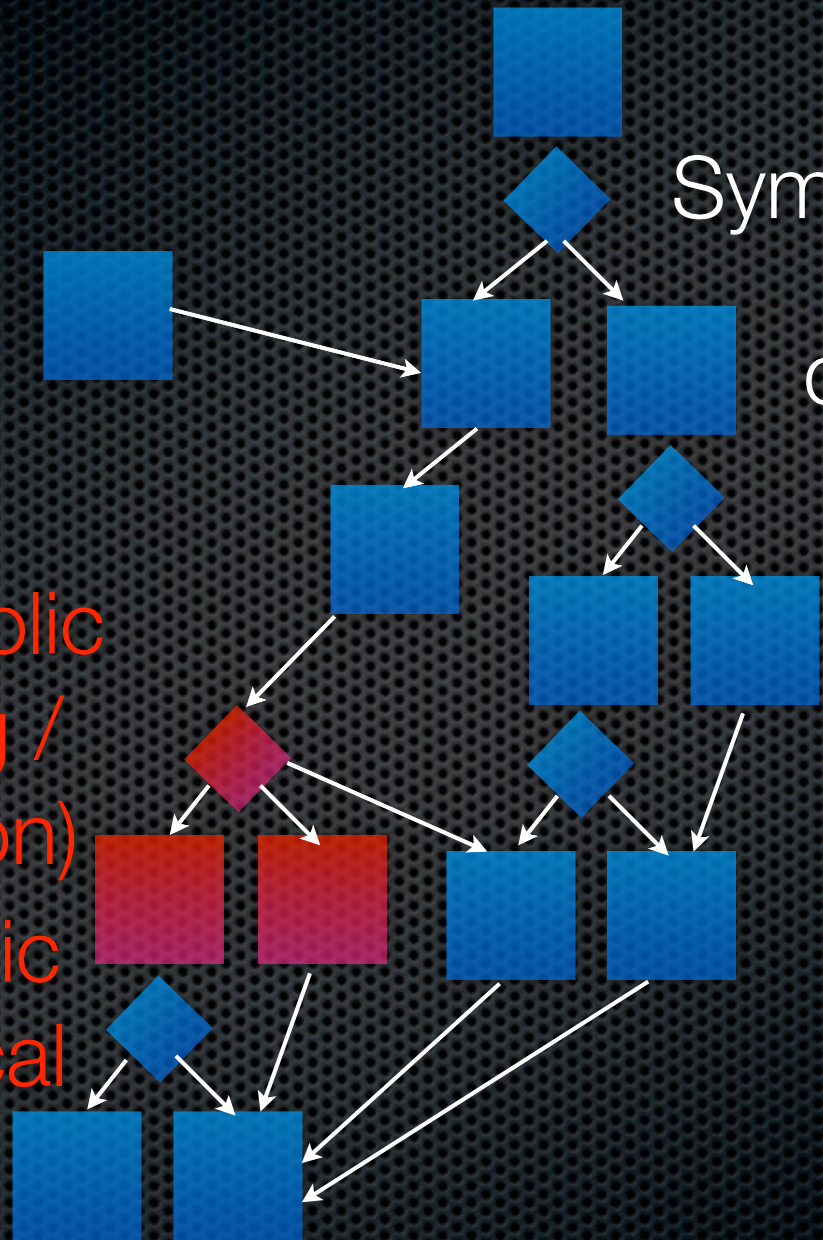
Production Rule System



The Argument

- **Constraints:** Architectural advances require further constraints
- **Scaling it up:** Complex tasks, broad coverage of behavior (e.g., linguistic), use of microstrategies and predictive modeling may serve to motivate further architectural constraints
- **Difficulties:** ACT-R is heavily constrained already, and models are difficult to develop, reuse and exchange
- **We need to produce models at a higher abstraction level**
    - However, we'd like to leverage successful cognitive modules, describing memory retention, cue-based retrieval, routinization, reinforcement learning

Cognitive Strategy



A real-life model

```
)


;; we're at the left sentence boundary
(p at-sentence-start
  =goal>
    ISA synsem
    STATE adjoin
    CONTEXT-TYPE-LEFT nil
    CONTEXT-TYPE-COMB nil
    CONTEXT-TYPE nil
    TYPE =wanted-type
 ==>
  =goal>
    STATE split-type
  +retrieval>
    ISA syntype
    SYN  =wanted-type
)



(p adjoin-forward-application
   =goal>
    ISA synsem
    STATE adjoin
    CONTEXT-TYPE-LEFT  =resulting-type
    CONTEXT-TYPE-COMB  forward
    CONTEXT-TYPE-RIGHT =wanted-type
    ;; the left context needs to be of a certain type
    TYPE          =wanted-type
==>
;; now we need to split up resulting type to fill it into the GOAL

  =goal>
    STATE split-type

  +retrieval>
    ISA syntype
    SYN =resulting-type
)

(p adjoin-backward-application
   =goal>
    ISA synsem
    STATE adjoin
```

```
    ISA          synsem
    STATE         adjoined
    TYPE          nil
    LEX           =sfcform
    STACKED-CONTEXT-TYPE =sct
    STACKED-CONTEXT-TYPE-LEFT  =sctl
    STACKED-CONTEXT-TYPE-COMB =sctc
    STACKED-CONTEXT-TYPE-RIGHT =sctr
    CONTEXT-TYPE =ct
    CONTEXT-TYPE-LEFT  =ctl
    CONTEXT-TYPE-COMB  =ctc
    CONTEXT-TYPE-RIGHT =ctr
 ==>
  =goal>
    STATE adjoin
    CONTEXT-TYPE =sct
    CONTEXT-TYPE-LEFT  =sctl
    CONTEXT-TYPE-COMB  =sctc
    CONTEXT-TYPE-RIGHT =sctr
    TYPE =ct
    TYPE-LEFT  =ctl
    TYPE-COMB  =ctc
    TYPE-RIGHT =ctr

)


(p after-adjoin
  =goal>
    ISA          synsem
    STATE         adjoined
    LEX           =sfcform

    CONTEXT-TYPE =ct
 ==>

  +retrieval>
    ISA syntype ;; doesn't matter what
    :recently-retrieved reset

  !output! (Context-type =ct)
  !eval! (progn
             (setq *sentence* (format nil "~A ~A" *sentence* =sfcform))
             (if (not *be-quiet*) (print-warning "~A ~A" =sfcform =ct))
              (when (equal =sfcform "to")
                (setq *to-has-been-said* t))
              )
  =goal>
    STATE realize
```

```
(p split-basicsyntype
  =goal>
    ISA          synsem
    STATE         split-type
  =retrieval>
    ISA   syntype
    CLASS basic
    SYN   =retrievedtype
    ATTRACT nil
 ==>
  =goal>
    STATE adjoined  ;; go back to realize
    CONTEXT-TYPE-LEFT  nil
    CONTEXT-TYPE-COMB  nil
    CONTEXT-TYPE-RIGHT nil
    CONTEXT-TYPE =retrievedtype
    TYPE nil
    ATTRACT nil
)
(p split-basicsyntype-with-attract
  =goal>
    ISA          synsem
    STATE         split-type
  =retrieval>
    ISA   syntype
    CLASS basic
    SYN   =retrievedtype
    ATTRACT =attracted
 ==>
  =goal>
    STATE adjoined  ;; go back to realize
    CONTEXT-TYPE-LEFT  nil
    CONTEXT-TYPE-COMB  nil
    CONTEXT-TYPE-RIGHT nil
    CONTEXT-TYPE =retrievedtype
    TYPE nil
    ATTRACT =attracted
)
```

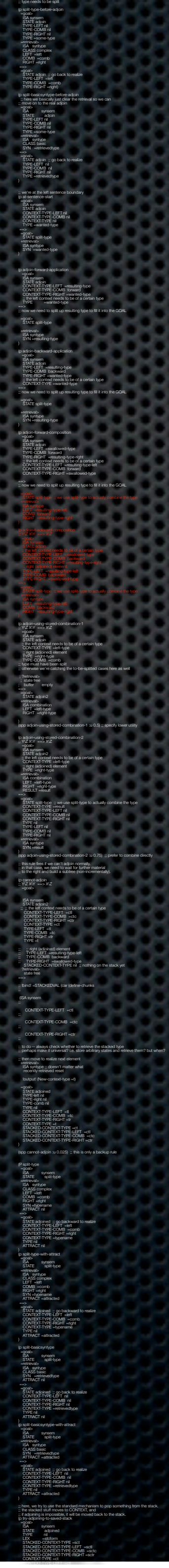
```
  =goal>
    STATE adjoined
    TYPE-left nil
    TYPE-right nil
    TYPE-comb nil
    TYPE nil
    CONTEXT-TYPE-LEFT  =tl
    CONTEXT-TYPE-COMB  =tc
    CONTEXT-TYPE-RIGHT =tr
    CONTEXT-TYPE =t
    STACKED-CONTEXT-TYPE =ct
    STACKED-CONTEXT-TYPE-LEFT
    STACKED-CONTEXT-TYPE-COMB
    STACKED-CONTEXT-TYPE-RIGHT
)

(spp cannot-adjoin :u 0.025)  ;; this is


(P split-type
  =goal>
    ISA          synsem
    STATE         split-type
  =retrieval>
    ISA   syntype
    CLASS complex
    LEFT  =left
    COMB  =comb
    RIGHT =right
    SYN =typename
    ATTRACT nil
 ==>
  =goal>
    STATE adjoined  ;; go backward to
    CONTEXT-TYPE-LEFT  =left
    CONTEXT-TYPE-COMB  =comb
    CONTEXT-TYPE-RIGHT =right
    CONTEXT-TYPE =typename
    TYPE nil
    ATTRACT nil
)
(p split-type-with-attract
  =goal>
    ISA          synsem
    STATE         split-type
```

Priming Model

Crucial request of a chunk from declarative memory

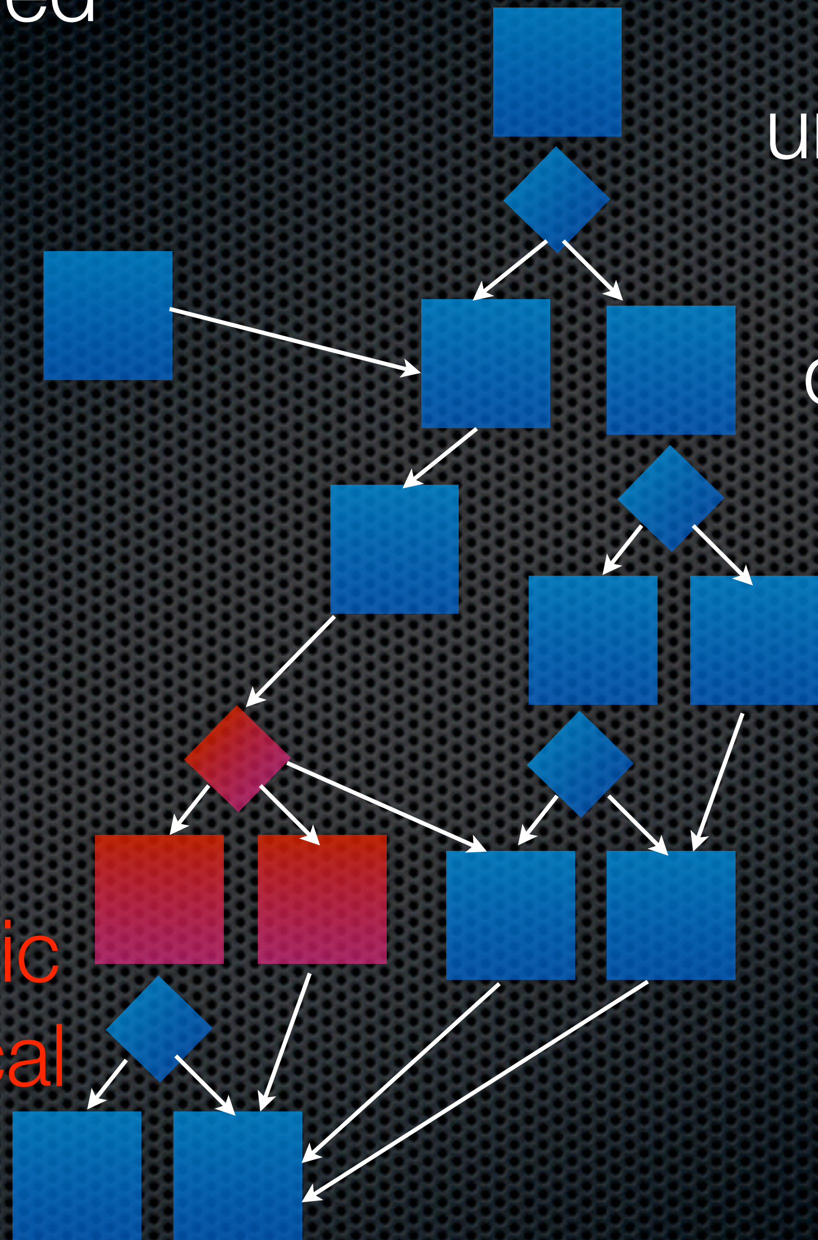


- Only a small portion of the model explains the behavioral data at hand
- The rest explains that the task can be accomplished in principle with a parallel architecture and with specific cognitive representations (chunk types)

The Argument

- **Constraints:** Architectural advances require further constraints
- **Scaling it up:** Complex tasks, broad coverage of behavior (e.g., linguistic), use of microstrategies and predictive modeling may serve to motivate further architectural constraints
- **Difficulties:** ACT-R is heavily constrained already, and models are difficult to develop, reuse and exchange
- **Abstraction:** To implement those, we need to produce models at a higher abstraction level
- **Underspecification is the key to focus on verifiable claims, and to avoid overfitting by fitting free parameters to data**

Underspecified models



underspecify:

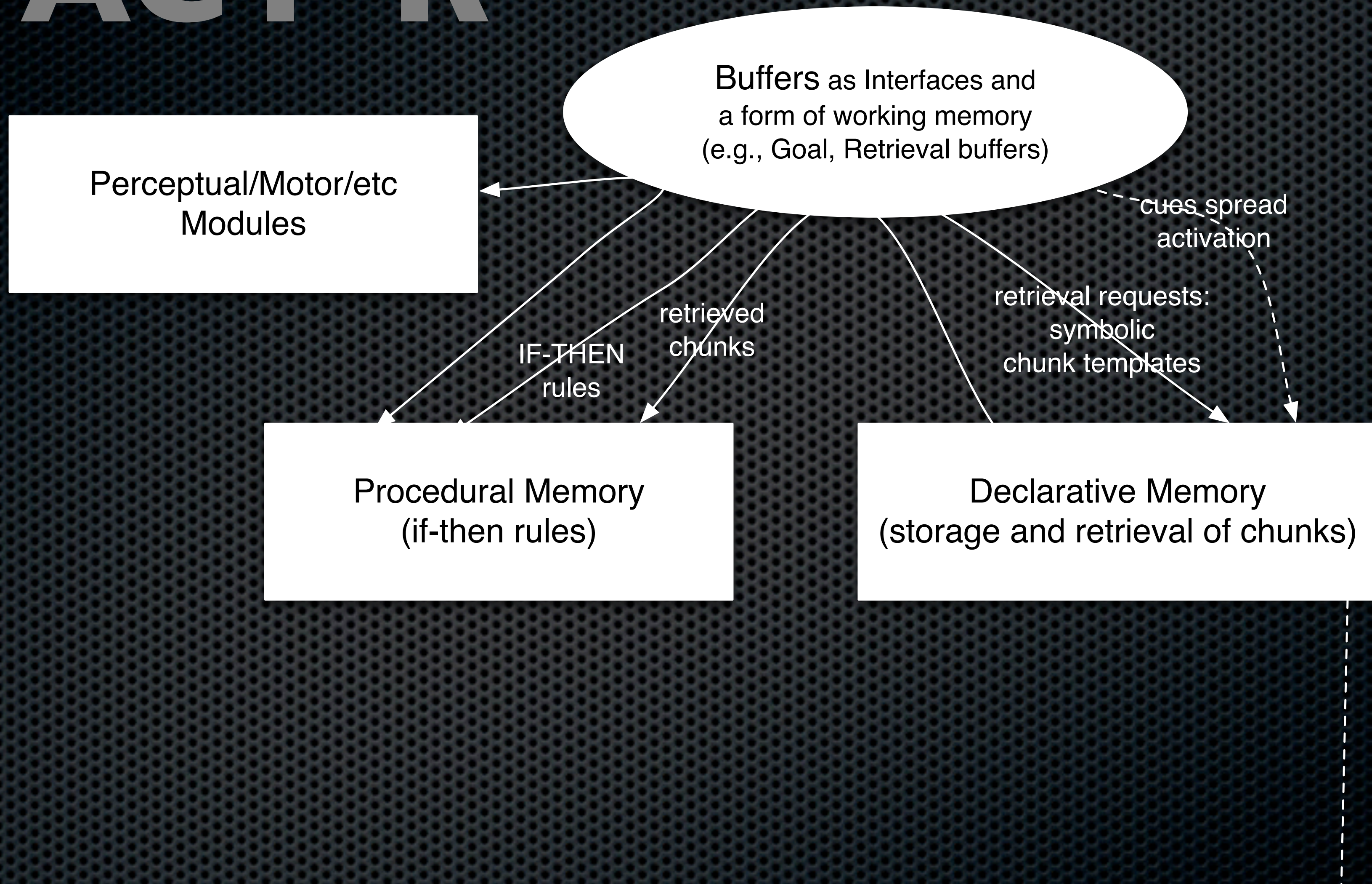
deterministic

specify:

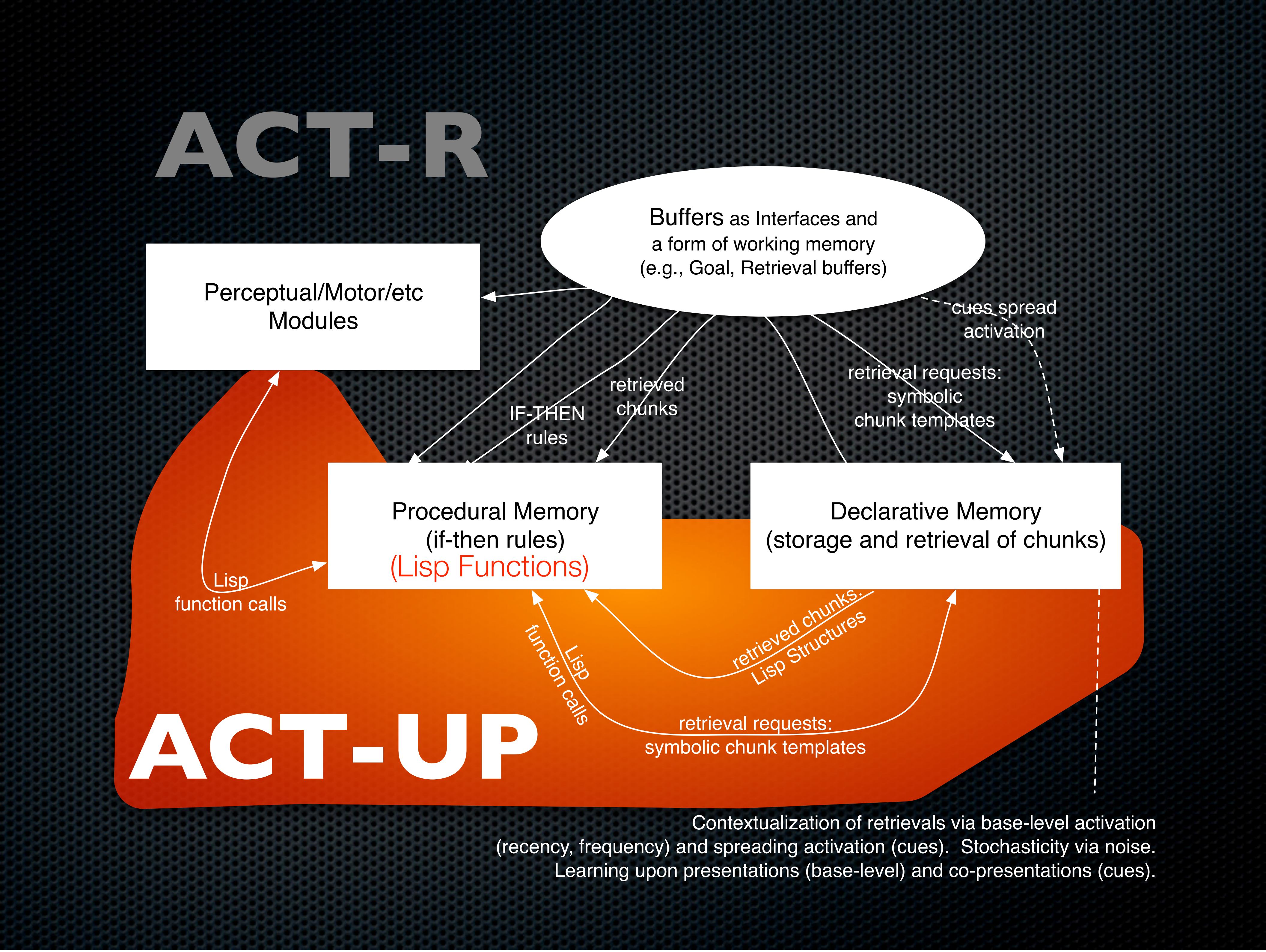
non-deterministic

explains empirical variance

ACT-R



Contextualization of retrievals via base-level activation
(recency, frequency) and spreading activation (cues). Stochasticity via noise.
Learning upon presentations (base-level) and co-presentations (cues).


ACT-R
Buffers as Interfaces and
a form of working memory
(e.g., Goal, Retrieval buffers)
Perceptual/Motor/etc
Modules
cues spread
activation
retrieved
chunks
IF-THEN
rules
retrieval requests:
symbolic
chunk templates
Procedural Memory
(if-then rules)
(Lisp Functions)
Declarative Memory
(storage and retrieval of chunks)
Lisp
function calls
Lisp
function calls
retrieved chunks:
Lisp Structures
retrieval requests:
symbolic chunk templates
ACT-UP
Contextualization of retrievals via base-level activation
(recency, frequency) and spreading activation (cues). Stochasticity via noise.
Learning upon presentations (base-level) and co-presentations (cues).

ACT-UP

- A stand-alone system on the basis of Common Lisp
- targets an audience that can write simple Lisp programs (unlike, e.g., CogTool)
- Toolbox approach to ACT-R
  - light-weight: it's a Lisp library
  - does not produce production rules (ACT-R/Lisa, ACT-Simple, CogTool)
- Not aimed at implementing all constraints of ACT-R 6 (unlike Java ACT-R, Python ACT-R)

DM

- `define-chunk-type'
  - types are optional
- `make-count-order'
- `learn-chunk'
- `defrule'
- `retrieve-chunk'
- `count-order-second'

ACT-UP Code

```
;; ACT-R parameters
(setq *lf* .05)
(setq *rt* -1)

;;;; Defining chunk type

(define-chunk-type count-order first second)
```

ACT-UP is not ACT-R 6...

- ACT-UP Interface is synchronous
  - Serial execution
  - Deterministic strategies defined as programs
- Parallelism (e.g., perceptual/motor modules) possible [not implemented]
- Non-deterministic rule choice is possible
  - Reinforcement-learning as in ACT-R 6

PM / Utility learning

- `choose-coin'
- calls either `decide-heads or `decide-tails'
- `assign-reward' reinforces the decision
- Exact production rules are underspecified,
    - but decision-making point is explicit
- Choice model replicates ACT-R and empirical results

```lisp
;; Experimental environment
(defun toss-coin ()
  (if (< (random 1.0) .9) 'heads 'tails))

;; The Model
;;;; Rules that return the choice as symbol heads or tails

(defrule decide-tails ()
  :group choose-coin
  'tails)

(defrule decide-heads ()
  :group choose-coin
  'heads)
```

Competition set "choose-coin"

Rule compilation

```
(defrule count-model (arg1 arg2)
  "Count from ARG1 to ARG1.
ARG1 is the starting point and ARG2 is the ending point.
Each increment is 1 unit."
  (speak arg1)
  (if (not (eq arg1 arg2))
      (let ((p (retrieve-chunk (list :chunk-type 'count-order
                                     :first arg1))))
        (if p
            (count-model (count-order-second p) arg2)))
      ;; else return end point
      arg2))
```

- (count-model 1 3) --> 3 (speak: “1”, “2”, “3”)
- *compiled:*
  (count-model 1 3) --> 3 (cached, no side-effects)
- ACT-R utility propagation mechanism applies

Rule compilation

```
(defrule ptmodel (word)
  "Form past-tense of WORD."
  :group past-tense-model
  (let ((q (form-past-tense word)))
    (if q
        (if (eq (third q) 'blank)
            (assign-reward 5.0)
            (assign-reward 4.2))
        (assign-reward 3.9))
    q))
```

ACT-UP Code

Rule compilation

- *side-effects:*
- retrieval from DM
- DM learning

ACT-UP Code

```
;;; Strategies
;;; All of them take a word as input and
;;; return a list with verb, stem, and suffix.

(defrule strategy-without-analogy (word)
  "Retrieve memorized past tense form for WORD."
  :group form-past-tense
  (let ((dec (retrieve-chunk (list :chunk-type 'pasttense :verb word))))
    (when dec  ;; retrieved?
      (learn-chunk dec)
      (pass-time 0.05)
      (list word (pasttense-stem dec) (pasttense-suffix dec)))))

(defrule strategy-with-analogy (word)
  "Retrieve some past tense form, using analogy."
  :group form-past-tense
  (let ((dec (retrieve-chunk (list :chunk-type 'pasttense))))
    (when dec  ;; retrieved?
      (learn-chunk dec)
      (pass-time 0.05)
      (list word (pasttense-stem dec) (pasttense-suffix dec)))))
```

Rule compilation

- (form-past-tense “follow”)
    - retrieval from DM by analogy: start,-ed
    - learning: follow, -ed

```
(defrule strategy-without-analogy (word)
  "Retrieve memorized past tense form for WORD."
  :group form-past-tense
```

- (form-past-tense “follow”) --> (follow -ed)
    - cached result
    - stored as ‘compiled rule’ with associated utility
    - **no** DM retrieval/learning are executed.
- (past-tense-model “follow”) --> (follow -ed)
    - side-steps reward assignment as well

```
(defrule ptmodel (word)
  "Form past-tense of WORD."
  :group past-tense-model
```

Debugging

```
(defrule count-model (arg1 arg2)
  "Count from ARG1 to ARG1.
ARG1 is the starting point and ARG2 is the ending point.
Each increment is 1 unit."
  (speak arg1)
  (if (not (eq arg1 arg2))
      (let ((p (debug-detail (retrieve-chunk (list :chunk-type 'count-order
                                                   :first arg1)))))
        (if p
            (count-model (count-order-second p) arg2)))
      ;; else return end point
      arg2))
```

Debugging

```
CL-USER> (debug-detail (do-it 1))

make-match-chunk (make-TYPE*): No such chunk in DM.  Returning new chunk (not in DM) of name LOSE
Presentation of chunk LOSE (MP: NIL t=72761.26.  M: MODEL521436, t=0.
Implicitly creating chunk of name LOST.
Presentation of chunk LOST (MP: NIL t=72761.26.  M: MODEL521436, t=0.
Implicitly creating chunk of name BLANK.
Presentation of chunk BLANK (MP: NIL t=72761.305.  M: MODEL521436, t=72761.305.
make-match-chunk (make-TYPE*): No such chunk in DM.  Returning new chunk (not in DM) of name HAVE
Presentation of chunk HAVE (MP: NIL t=72761.445.  M: MODEL521436, t=72761.445.
Implicitly creating chunk of name HAD.
Presentation of chunk HAD (MP: NIL t=72761.445.  M: MODEL521436, t=72761.445.
Group PAST-TENSE-MODEL with 1+0 matching rules, choosing rule PTMODEL (Utility 5.0709996)
Group FORM-PAST-TENSE with 3+0 matching rules, choosing rule STRATEGY-WITHOUT-ANALOGY (Utility 5.225957)
retrieve-chunk:
   spec: (CHUNK-TYPE PASTTENSE VERB GET)
  cues: NIL
  pmat: NIL
filtered 0 matching chunks.
retrieved none out of 0 matching chunks.
NIL
Assigning reward 3.9
Assigning reward 3.853125 to STRATEGY-WITHOUT-ANALOGY. STRATEGY-WITH-ANALOGY remains best regular rule in group FORM-PAST-TENSE.
Assigning reward 0.0 to PTMODEL. Best regular rule among alternatives in group PAST-TENSE-MODEL!
NIL
CL-USER>
```

Implemented Models

- 10 Classic models implemented:
  - count, addition, siegler, zbrodoff, paired, fan, sticks, semantic, choice, past-tense

* past-tense not yet complete

Efficiency

- Sentence production (syntactic priming) model
  - 30 productions in ACT-R, 720 lines of code
  - 82 lines of code in ACT-UP (3 work-days)
  - ACT-R 6: 14 sentences/second
  - ACT-UP: 380 sentences/second

Scalability

- Language evolution model
  - Simulates domain vocabulary emergence (ICCM 2009, JCSR 1010)
  - 40 production rules in ACT-R (could not prototype)
  - 8 participants interacting in communities
- In larger community networks: 1000 agents, 84M interactions (about 1 minute sim. time each), 37 CPU hours

Rapid prototyping/Reuse

- Dynamic Stocks&Flows model (JAGI 2010)
  - Competition entry, model written in < 1 person-month
  - Instance-based learning (IBL, Gonzales&Lebiere 2003)
  - Blending (Wallach&Lebiere 2003)
  - free parameters (timing) estimated from example data
  - Model generalized to novel conditions
    - (.... NOT. but it did so better than others.)
- Same IBL/blending micro-strategy was re-used directly in a *Lemonade Stand Game* entry to a 2009 competition (BRIMS 2010)

Drawbacks

- Less established code-base than ACT-R 6
- Lisp
- Lack of architectural timing predictions from rule matching
- Lack of parallelism (planned: fall 2010)
- lack of perception/motor modules
  - Will be available in ACT/Simple-style interface (Salvucci&Lee 2003)

Beta-Test

- **Limited Release** of ACT-UP test version
  - comes with 10 example models
  - 4 tutorials (paralleling the ACT-R 6 ones)
  - Full API documentation plus *How-do-I...* document
- Testing period: September-October 2010
- Task: implement 1-2 models of your own
- Review letter requested (journal-review style)

Thank you

- Further, published&in-press models to demonstrate efficiency, scalability, rapid prototyping, and reuse
Come see our ICCM Poster (Saturday 5pm)
- Details: ICCM 2010 paper (Reitter&Lebiere)